

Module 215

Streamflow

**Engineering
Hydrology Training Series**

Module 215—Streamflow

National Employee Development Center
Natural Resources Conservation Service
United States Department of Agriculture
July 1999

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Preface

This module consists of a study guide. It is intended as a self-study package.

The Study Guide is designed as a reference. It contains the lesson material, two activities, and a certificate of completion.

The module is intended as an advanced level study of Streamflow (200 series). A more general module (115) is available as a review if you aren't thoroughly familiar with NRCS streamflow data, sources of data, streamflow variability, riparian and appropriation water rights, and state agencies responsible for water laws.

Proceed through this module at your own pace. You should understand each section before moving to the next. If you have questions or need help, please request assistance from your supervisor. If your supervisor cannot clear up the problem, he or she will, through channels, contact the state-assigned resource person. The resource person is familiar with the material and should be able to answer any question you may have.

Acknowledgment

The design and development of this training program is the result of a concerted effort by practicing engineers in the National Resources Conservation Service (NRCS). The contributions of many technical and procedural reviews have helped to make this program one that will provide needed hydrology/hydraulic skills to NRCS employees.

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Module Description

Objectives

Upon completion of this module, the participant will be able to:

- Describe several uses of streamflow data appropriate for participant's region.
- Describe the drought analysis techniques applicable to the participant's region.
- List the methods for measuring streamflow.
- Explain water laws applicable to the participant's state.
- Perform at ASK Level 3 (Perform with Supervision).

Prerequisite

Module 115—Streamflow

References

Participant should have the following reference available to use with this module: NEH 4, *Hydrology*, Chapter 18, Frequency methods.

Duration

Trainee should take as long as necessary to complete the module.
Approximate completion time for the module is two hours.

Eligibility

This module is intended for all NRCS employees who use streamflow data and need a thorough introduction to the subject.

Overview

Use of streamflow data (peakflow, annual runoff, and volume-duration probability studies), drought analysis technique, direct and indirect methods of measuring streamflow, and applicable water laws (riparian, prior appropriations, Pueblo Rights).

Module 215—Streamflow

Introduction

This module is intended as an advanced level study of Streamflow. A more general module (115) is available as a review if you aren't thoroughly familiar with NRCS Streamflow data, sources of data, streamflow variability, riparian and appropriation water rights, and state agencies responsible for water laws.

Before beginning, be sure you have a copy of NEH 4, Chapter 18 handy.

Upon completion of this module, you will be able to:



- Describe several uses of streamflow data
- Describe the drought analysis techniques applicable to the NRCS.
- List and describe methods that are used to measure streamflow.
- Explain the differences between the two major doctrines of water law.

Now, let's start with the first objective.

The three major uses of streamflow data by the National Resources Conservation Service are:

- Peakflow studies
- Volume-duration probability studies
- Annual runoff studies

Each of these studies are covered in this section.

Peakflow studies

Annual series frequency analysis

The analysis of streamflow data to determine flood flow frequencies is essential in the design of large NRCS jobs and for project work in which the NRCS is involved. For project planning, NRCS should have a consistent and accurate technique for estimation of flood flow frequencies.

NRCS has a long standing interest and involvement in Federal interagency efforts to systematize various aspects of flow frequency determination. The procedures outlined in chapter 18, NEH 4 are used.

The Pearson Type III distribution that has log transformation of flood data is recommended as a method for defining the annual flood series. The method of moments determines the statistical parameters of the cumulative distribution from station data. An example of the Log-Pearson Type III distribution is in chapter 18, NEH 4.

Partial duration frequency series

If more than one flood per year must be considered, a partial duration series may be the appropriate basis to assure that all of the events of interest are evaluated, including at least one event per period. The major problem in using this series is to define flood events to ensure that all events are independent.

Establishing an empirical basis for separating flood events is common practice. The basis for separation depends upon the investigator and the intended use. The U.S. Geological Survey uses bankflow discharge or the minimum annual peak to ensure at least one peak discharge.

Regional analysis

Because many watersheds analyzed by the NRCS are in locations for which little measured streamflow data are available, techniques have been developed to transfer, or regionalize, available streamflow data to other similar locations. One purpose of regionalization is to synthesize the frequency curve at an ungaged location or at a location where data are inadequate for developing a frequency curve. Most common forms of regionalization use watershed and hydrometeorological characteristics as predictor variables in multiple regression analysis. An example, in the simplest form, might be:

$$q_{p10} = 300A^{0.9}$$

where:

q_{p10} = The peak discharge,

A = The watershed area.

USGS regional studies

In many areas of the United States, USGS has made regional studies of streamflow. These studies are usually regression analyses of existing streamflows. Separate sets of regression equations are then used to define annual floods for various portions of the study area. Such items as drainage area, annual precipitation, forest cover, mean basin elevation, main channel slope, and many other variables have been used in multiple regressions to produce an equation that gives acceptable results on ungaged streams.

Volume—Duration Probability Studies

Another major use of streamflow data is in volume duration probability studies. USGS Water Supply papers not only give the daily values but the accumulated monthly values of volume flow.

Frequency analysis

The frequency analysis of the volume duration flows is one method used to determine irrigation water availability in many western areas.

Regional analysis

Regional volume-duration probability studies can be used for ungaged streams. Regional analysis in its simplest form is developed as follows:

1. Select nearby gaged watersheds that are climatically and physically similar to the ungaged watershed. Together these watersheds make up a region, thus giving the method its name.
2. Construct frequency lines for the volume duration of the gaged watershed.
3. Using log paper, plot the runoff volume for selected frequencies of each gaged watershed against its drainage area. Make straight-line relationships for each frequency.
4. Construct a frequency line for the ungaged watershed by entering the plot drainage area, finding the magnitudes at each line relationship, plotting the magnitudes at their proper place on probability paper, and drawing the frequency line through the points.
5. Apply the frequency line to step 4 in the procedure for present conditions.

Low flow studies

In some cases low flow may be the controlling parameter in project design. For instance, the number of acres that can be irrigated from a stream may be dependent on the frequency with which a low flow occurs. If the water is not available to irrigate on a cost-effective basis, there would be no reason to irrigate more land. For a power plant, the low flow may be the controlling parameter in designing a system for continuous use. The 7-day, 10-year low flow is often used to establish the minimum environmentally acceptable low flow. Many states have established acceptable low flow standards for streams.

The U.S. Army Corps of Engineers often uses a minimum flow to establish the need to obtain a 404 permit.

Environmental Impact Statement (EIS) studies

In some project type reports, EIS studies require the obtaining of such additional flow data as mean annual discharge, mean monthly flow, and number of days that have zero flow.

Annual Runoff Studies

Frequency analysis

As with peakflow studies, frequency analyses can be made for annual runoff volumes. The Pearson Type III distribution that has log transformation of volume data is recommended as a basis for defining the annual volume series. This procedure was discussed previously under peakflow studies.

Regional analysis

For watershed areas where little or no runoff has been measured, a regional analysis can be performed on streams that have similar slopes and aspects. A plot of watershed area versus annual flow can be made, and an enveloping curve can be drawn giving approximate maximum runoff.

USGS regional analysis

The United States Geological Survey (USGS) has made regional studies of annual runoff. These studies are usually regression analyses of existing streamflows. Multiple regression equations are then used to define the annual runoff volumes for various portions of the study area. Such items as drainage area, annual precipitation, forest cover, mean basin elevation, main channel slope, and other variables have been used in multiple regressions to produce an equation that gives acceptable results on ungaged streams.

USGS WATSTORE file

The USGS measures the current quantity, quality, distribution, and movement of the Nation's surface and underground water resources. USGS also maintains a large computerized storage and retrieval system called WATSTORE. In addition to its data processing storage and retrieval capabilities, WATSTORE has the capability of providing computer printed tables, computer printed graphs, statistical analysis of data, and digital plots. The WATSTORE User Guide describes the system and how it operates.

WATSTORE is available to other Federal agencies and selected cooperators of USGS who require or use water data, or both. Authorization to use WATSTORE can be obtained from the Chief Hydrologist, USGS, National Center, Mail Stop 409, Reston, VA 22092. USGS training classes are available periodically on use of WATSTORE data files.

Other agencies

USDA's Agricultural Research Service (ARS) and Forest Service also obtain streamflow data. ARS maintains its own data base. Annual runoff can be obtained from the Bureau of Reclamation. Many of its irrigation projects maintain stream gages and have total runoff data from various watersheds. Universities often have pilot study watersheds from which they gather annual runoff data. State agencies, such as state engineering or departments of ecology, maintain stream gages and have data on annual runoff. The U.S. Army Corps of Engineers has annual runoff data for watersheds where they have projects.

Activity 1



At this time, complete Activity 1 in your Study Guide to review the material just covered. When you have finished, compare your answers with the solutions provided near the back of this module. When you are satisfied that you understand the material, continue with Study Guide text.

Activity 1



1. What are the three major uses of streamflow data?

a. _____

b. _____

c. _____

2. What procedure is used by NRCS to determine flow frequency?

3. What agency is responsible for most peak streamflow studies?

4. What is WATSTORE?

5. Explain how to make a volume-duration probability study using the regional analysis method.

a. _____

b. _____

c. _____

d. _____

e. _____

Drought Analysis Techniques

Drought can be considered as a strictly meteorological phenomenon. It can be evaluated as a meteorological phenomenon characterized by a prolonged and abnormal moisture deficiency. Not only does this approach avoid many complicating biological factors and arbitrary definitions, it enables one to derive a climatic analysis system in which drought severity is dependent on duration and magnitude of abnormal moisture deficiencies.

Because drought is a function of atmospheric motion, oceanic changes, continents, landforms, and other casual factors, and has many definitions, it is difficult to predict. Agricultural drought is probably the most important aspect of drought, but the problem is far more specialized and complicated than some. The study of agricultural drought immediately leads one into the realm of soil physics, plant physiology, and agricultural economics. A few of the more bizarre definitions for drought include those from the publication by Hudson and Hazen in 1964: Bali, 6 days without rain is a drought; Libya, 2 years without rain is a drought; Egypt, any year the Nile River does not flood is a drought regardless of rainfall.

Palmer Index

One of the more useful methods of defining a drought is the Palmer Drought index (Palmer, 1965). This index is a function of meteorological parameters and soil moisture. It presents an objective numerical approach to drought and permits an objective evaluation of climatic events. Severity of an agricultural drought is defined in terms of magnitude of computed evapotranspiration deficit expressed as crop moisture index. Negative values of the crop moisture index mean that evapotranspiration has been abnormally deficit. The United States is mapped on a weekly basis using this index.

Palmer's Index treats drought severity as a function of the accumulated weighted difference between actual precipitation and precipitation requirements. Index values can be correlated with general crop condition, forest fire danger, water supply, and economic disruption. Index values are summarized by large areal climatic division.

Using a Palmer Index, a value of zero would be considered near normal. A negative number would indicate some type of drought. A negative 4 or less would indicate extreme drought. This is shown in the following chart:

Classes for Wet and Dry Periods	
Monthly Index Value	Class
≥ 4.00	extremely wet
3.00 to 3.99	very wet
2.00 to 2.99	moderately wet
1.00 to 1.99	slightly wet
0.50 to 0.99	incipient wet spell
0.49 to 0.49	near normal
-0.50 to 0.99	incipient drought
-1.00 to -1.99	mild drought
-2.00 to -2.99	moderate drought
-3.00 to -3.99	severe drought
≤ -4.00	extreme drought

Streamflow Analysis

The Gumbre method analysis of drought problems uses a definition that “drought is the smallest annual value of mean daily river discharge”. The probability of a daily “smallest value” is found using the third asymptotic distribution, or a theory of extremes. This method assumes that:

- $n = 365$ is a large number, and
- daily streamflow values, although interdependent for few successive days, are independent for large periods.

As with flood problems, return period and characteristic drought are calculated. No attempt is made to calculate drought duration or the areal extent of drought.

Methods Of Measuring Streamflow

Direct Method

Direct method is the estimation of discharge by actual measurement of the stage or depth of water and estimation of average velocity of a cross section.

Stage Measurements

Crest Staff Gages

The simplest way to measure river stage is by means of a staff gage. The scale is set so that a portion of it is immersed in the water at all times. The gage may consist of a single vertical scale attached to a bridge pier, piling, wharf, or other structure that extends into the low water channel of the stream. If no suitable structure exists in a location that is accessible at all stages, a sectional staff gage may be used. Short sections of staff are mounted on available structures or on specially constructed supports in such a way that one section is always accessible. An alternative to the sectional staff is an inclining staff gage. It is placed on the slope of the streambank and graduated so that the scale reads directly in vertical depth. The crest staff gage requires someone to read it on a periodical basis.

Continuous Stage Gages—average stream velocity determination

More recent stream gages include the continuous stage gage where a record of streamflow is scribed on a strip chart. To determine volume of flow using the continuous recording chart, a stage discharge relationship must be built for the site.

Bubble Gages

Manometers operate on the principle that a difference in pressure between ends of the manometer displaces the free surface of a liquid mercury column. Displacement of the liquid mercury develops a head sufficient to balance the pressure. The pressure-cup reservoir on the manometer is driven by a servo motor, actuated by a float switch, to a position that develops a sufficient height of mercury to balance the pressure. The float switch operates within a narrow lead band and actuates the motor until a null position is developed when the pressure is balanced. Activation of the float switch is a direct consequence of movement of the free surface of mercury when pressures across the manometer change as a result of variations in stream level. A counter displays the stage (height), in feet of water, which is recorded on an analog or digital recorder, or both. The manometer assembly converts pressure in the sensing element of the stage-indicating and recording mechanism.

Velocity Measurements

Sonic

The acoustical velocity meter works on the principle that point-to-point travel time of sound is longer upstream than downstream and that travel times can be measured accurately by electronic devices. Measurement of velocity is along an acoustic path set 30 to 45 degrees diagonal to streamflow. Commercial systems that measure streamflow use the time of travel method to determine velocity. Fluctuation in the speed of sound caused by changes in water density brilliance are compensated for by methods used to calculate velocity.

Dye (tracing)

Tracing is not new, but the extensive use of fluorescent dyes as a tracer is less than a decade old. In the past floats, chemical salts, and actual contaminants have been used as tracers. After World War II radio isotopes, such as tritium, gained favor as tracers, but their uses were fairly limited by handling problems, special training required, and a general lack of understanding by the public.

Nearly all applications of dye tracing include an introduction of dye into a water body, subsequent collection of water samples over time and space, and determination of the concentration of dye by means of a fluorometer. Dosing and sampling procedures are generally the same for most applications. For additional information on this subject, see *Techniques of Water-Resources Investigations of the U.S. Geological Survey, Chapter A-12, Fluorometric Procedures for Dye Tracing*.

Current Meter

The most direct method for measuring streamflow in natural streams is by using a current meter to obtain velocities at a selected point through a cross section. From these velocities and associated cross-sectional areas, the discharge can be computed for various stages on the rising and falling side of a flood flow.

Indirect Method

Indirect determination of discharge makes use of the energy equation for computing streamflow and generally is made after an event has occurred.

Culverts

Streamflow measurements can be made at existing culverts based upon culvert hydraulics and field measurements (head on the inlet and outlet of culverts).

Bridges

Bridges can be used as measuring points for streamflow. Elevations of the upstream water surface, along with the cross section data of the bridge and pier conformation, are needed to make the hydraulic computations necessary to compute streamflow.

Other Restrictions

Hydraulic computations can be made to determine flow at other restricted areas, such as weirs and orifices.

Slope Area Methods

Determination of water surface profiles in open channels is made by using uniform flow equations involving solution of Manning's equation. Normally, three cross sections are obtained about 500 feet apart using known high water marks.

Applicable Water Laws

Two basic divergent doctrines regarding the right to use water exist, namely riparian and appropriation. They are recognized either separately or as a combination of both doctrines in different states. Both doctrines apply only to surface water in natural watercourses and to water in well defined underground streams.

Riparian Rights

The riparian doctrine, which is the principle of English common law, recognizes the right of a riparian owner to make reasonable use of streams flow, provided the water is used on riparian land. This doctrine exists in all the eastern states and is retained, in part, in a few western states. Because few eastern states have statutory laws governing water rights, this doctrine is based mostly on court decisions. Riparian land is that which is contiguous to a stream or other body of surface water.

Key point



*The right of land ownership includes the right of access to and use of the water, **and this right is not lost by nonuse.***

Reasonable use of water generally implies that the landowner may use all that he needs for drinking, household purposes, and watering livestock. Where large herds are watered or where irrigation is practiced, a riparian owner is not permitted to exhaust the remainder of the stream, but he may use only his equitable share of the flow in relation to the need of others similarly situated.

Doctrine of Prior Appropriation

The doctrine of prior appropriation is based on the priority of development and use. For example, the first to develop and put water to beneficial use has the prior right to continue its use. This principle assumes that it is better to let the individuals who initially developed and used the watercourse take all the water rather than to distribute inadequate amounts to several owners.

Key point



Water rights are not limited to riparian land and may be lost by abandonment or nonuse.

The right of appropriation is acquired mainly by filing a claim in accordance with laws of the state. The water must be put to some beneficial use, but the appropriator has the right to all water required to satisfy his needs at a given time and place.

All 17 Western States recognize this doctrine, although in some it is in combination with riparian doctrine. The right of appropriation applies specifically to Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, and Wyoming. A combination system is generally recognized in North Dakota, South Dakota, Nebraska, Kansas, Texas, California, and Washington. To a more limited extent, the combination system is also applicable to Oklahoma and Oregon.

Pueblo Rights

In California, old Spanish land grants contained water rights that went with the land. These are called Pueblo rights.

Transfer of Water Rights

Key point



Both riparian and appropriation water rights are considered as real property and may be bought and sold.

Riparian rights must remain with the land adjacent to the stream and may not be transferred. These rights transfer automatically with a land sale so long as the sold property is adjacent to the stream. However, if a parcel of land that is not adjacent to the stream but had benefited from riparian water rights is sold, riparian rights transfer only if specifically mentioned in the deed. Otherwise, they are lost to that land. A new land owner having riparian water rights should contact the state agency responsible for water rights to acknowledge the transfer and to see if any action concerning the transfer is required.

Appropriated water rights are usually granted after a person files an application for a permit with state water officials, accompanied by proper maps and description statements. Typically, the appropriator is granted a certification of appropriation, which is added to the state's list of water rights adjusted. Purchasers of appropriated water rights should contact state water officials to acknowledge the transfer and assure that the list of water rights is updated.

Activity 2



At this time, complete Activity 2 in your Study Guide to review the material just covered. When you have finished the Activity, compare your answers with the solutions provided. When you are satisfied that you understand the material, continue with the Study Guide text.

Activity 2



1. What is one of the most useful methods of defining a drought?

2. What is the basic definition used in the Gumbre method for analyzing drought?

3. Would going 18 months without rain in Libya indicate a drought? Explain.

4. What are the direct methods of measuring streamflow?

a. _____

b. _____

c. _____

d. _____

e. _____

5. What is the basic difference between riparian and prior appropriation water rights?

- a. _____

- b. _____

- c. _____

Summary

You have completed Module 215. Let's briefly review what you've covered. First, you found there were three main uses for streamflow data—peakflow studies, annual runoff studies, and volume-duration probability studies.

Next, you reviewed the three techniques used for drought analysis—Palmer Index, streamflow analyses, and soil moisture index.

Third, you covered methods, both direct and indirect, for measuring streamflow. Some of these direct methods were crest staff gages, continuous stage gages, bubble gages, sonic gages, and dyes. Indirect methods covered were culverts, bridges, and other restrictions.

And last, you reviewed two basic divergent doctrines regarding the right to use water—riparian and appropriation water rights.

If you are actively engaged in streamflow related activities, you will want to do further reading and research to fully develop yourself.

Retain this Study Guide as a reference until you are satisfied that you have successfully mastered all the methods covered. It will provide an easy review at any time if you should encounter a problem.

If you have had problems understanding the module or if you would like to take additional, related modules, contact your supervisor.

When you are satisfied that you have completed this module, remove the Certificate of Completion sheet (last page of the Study Guide), fill it out, and give it to your supervisor to submit, through channels, to your Training Officer.

Activity Solutions

Activity 1

1. What are the three major uses of streamflow data?

- a. *Peakflow studies*
- b. *Volume-duration probability studies*
- c. *Annual runoff studies*

2. What procedure is used by NRCS to determine flow frequency?

The Log-Pearson Type III distribution procedure

3. What agency is responsible for most peak streamflow studies?

The U.S. Geological Survey (USGS)

4. What is WATSTORE?

A large-scale, computerized storage and retrieval system that has the capability of providing computer printed tables and graphs, statistical analysis of data, and digital plots. WATSTORE contains the latest, most complete data available on quantity, quality, distribution, and movement of the Nation's surface and underground water resources.

5. Explain how to make a volume-duration probability study using the regional analysis method.
 - a. *Select a nearby, climatically and physically similar gaged watershed for comparison.*
 - b. *Construct frequency lines for the volume-duration of the gaged watersheds.*
 - c. *Using log paper and making straight line relationships for each frequency, plot the runoff volume for selected frequencies of each gaged watershed against its drainage area size.*
 - d. *Construct a frequency line for the ungaged watershed by entering the plot drainage area, finding the magnitudes at each line relationship, plotting the magnitude at their proper place on probability paper, and drawing the frequency line through the points.*
 - e. *Use present conditions and apply the frequency line to step d.*

Activity 2

1. What is one of the most useful methods of defining a drought?

Palmer Drought Index

2. What is the basic definition used in the Gumbre method for analyzing drought?

"Drought is the smallest annual values of mean daily river discharge"

3. Would going 18 months without rain in Libya indicate a drought? Explain.

No. According to a publication by Hudson and Hazen in 1964, 2 years without rain is a drought. This is based on a complicated study into the realm of soil physics, plant physiology, and agricultural economics.

4. What are the direct methods of measuring streamflow?
 - a. *crest staff gage*
 - b. *continuous stage gage*
 - c. *bubble gage*
 - d. *sonic-acoustical velocity meter*
 - e. *tracing (dye)*

5. What is the basic difference between riparian and prior appropriation water rights?
- a. *Riparian rights apply only to land adjoining the stream; appropriation rights do not.*
 - b. *Riparian rights are not lost by nonuse; appropriated rights are.*
 - c. *Where water is to be put to a beneficial use, a riparian user may not use more than an equitable share of the flow in relation to the need of others similarly situated; an appropriated water rights user has the right to all water required to satisfy his needs at a given time and place.*

Hydrology Training Series Module 215—Streamflow

Certificate of Completion

This is to certify that

_____ has completed Hydrology Training Series
Module 215—Streamflow

on _____ and should be credited with three hours of training.

Signed _____

Supervisor/Trainer

Participant

Completion of Hydrology Training Series
Module 215—Streamflow

is acknowledged and documented in the above-named employee's record.

Signed _____

Training Officer

Date _____

